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Calculating the dose rate of natural radioactivity in vegetables from an agricultural area. El Jadida, Morocco †

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Abstract: The present work aims to measure the natural radioactivity and annual effective dose in vegetables collected from an agricultural area in El-Jadida located in the Northwestern part of Morocco. The activity concentrations of ^{210}Pb, ^{226}Ra, and ^{40}K were determined using a high-resolution gamma spectrometry technique. The results show that the specific activities in vegetable samples of ^{210}Pb, ^{226}Ra, and ^{40}K vary between 3.44 ± 0.55 Bq.Kg^{-1} and 12.80 ± 0.57 Bq.Kg^{-1}; 2.25 ± 0.6 Bq.Kg^{-1} and 5.15 ± 0.60 Bq.Kg^{-1}, and between 507.5 ± 27.76 and 1808.6 ± 93.19 Bq.Kg $^{-1}$ respectively. The total annual effective doses calculated for investigated vegetable samples for Pb-210, Ra-226, and K-40 are 0.5997 mSv/y, 0.1202 mSv/y, and 0.4194 mSv/y respectively. The obtained values of natural radioactivity and annual effective dose for ^{210}Pb, ^{226}Ra, and ^{40}K in the vegetable of the El Jadida region are safe and do not exceed the International limit values.

Keywords: Radioactivity; Vegetable samples; Gamma Spectrometry System; Annual Effective Dose

1. Introduction

Measuring the radionuclides concentrations in vegetables is crucial for a precise determination of the radionuclides activities and human radiation exposure potential risks and effects. Radioactivity in the environment may have natural and artificial sources and their concentrations vary depending on the geographical and geological characteristics [1]. Humans are exposed both to external and internal radiation from these sources [2] through inhalation and/or ingestion of terrestrial radionuclides intake. The inhalation exposure dose is related to the presence of dust in air containing gamma rays radiations formed by the radioactive decay of unstable nuclei (^{226}Ra, ^{232}Th, and ^{40}K). Concerning the ingestion exposure dose it mainly results from the existence of radionuclides in food and drinking water [2].

It is worth noting that all foods enclose natural radionuclides in low quantities and are thus safe for human consumption [3]. However, the radionuclides concentration may vary within food categories such as meat, fish, vegetable, and fruit. In this sense monitoring and controlling the radioactivity levels and radiation exposure rate in vegetables is crucial to avoid potential risks and effects on humans. In this sense, the present study aims to calculate the dose rate of natural radioactivity in vegetables from El Jadida in Morocco.

Agricultural activity in the province of El Jadida is known as a dynamic and diversified activity (plant and animal production) in the region (Figure 1). The agricultural area, totaling 367.000 ha, is made up of a useful agricultural area of 280.000 ha, 68.000 ha of rangelands, and 19.000 ha of forests. Many studies have investigated the environmental quality and radioactivity pollution levels of the El-Jadida region and surrounding areas, in particular through using sediments [4,5], soil [6] water [7] and marine living organisms

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of the coastal system. A lot of data on Rns conc. were produced, but no data on radioactivity in soils and plants.

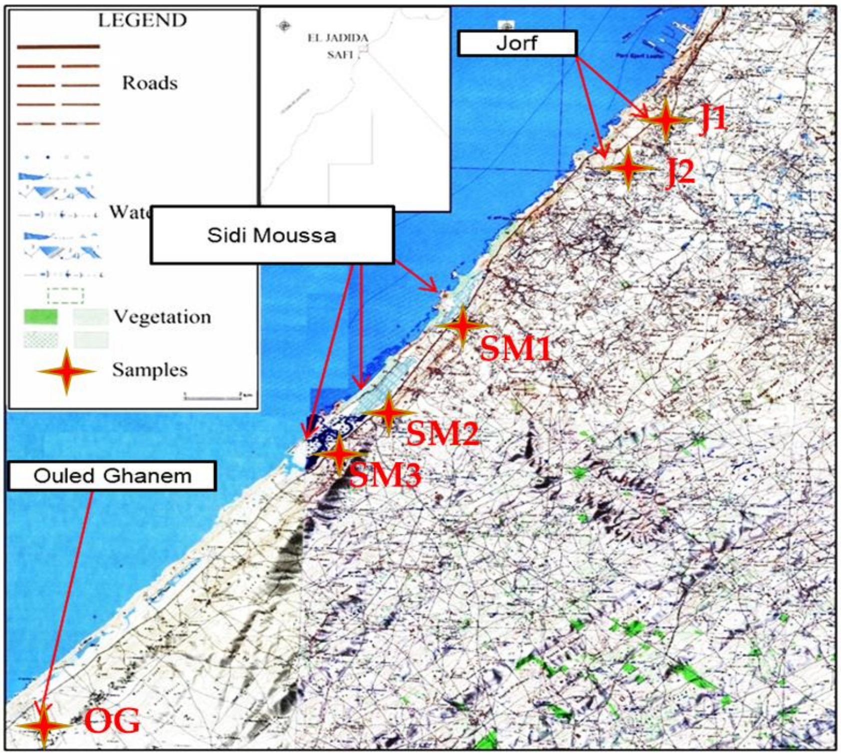

Figure 1. Study area location.

2. Materials and Methods

2.1. Sampling protocol

Samples were collected from six sites from 3 different locations (Jorf Lasfer (J1 & J2), Sidi Moussa (SM1, SM2 & SM3, and Ouled Ghanem (OG)) along the El Jadida Province (Fig.1). A mixture of food categories samples were collected from the study area including roots, stem, leaves, and fruits of vegetables (carrot, bean, broccoli, tomato, fennel, Pumpkin, Cabbage, Turnip), flowers (Mallow, sunflower). The collected vegetables are frequently consumed by local residents as well as the global Moroccan population. It is to be noted that almost all the selected vegetable samples are the main ingredients of the famous traditional dish in the El-Jadida region "Couscous" which means that the investigated vegetables in the present study are the most consumed by the Moroccan inhabitants.

2.2. Samples processing

2.2.1. Physical Preparation

The vegetable samples selected and collected from El Jadida province are the most frequently consumed by local residents. Samples were collected during the rainy season (February 2019). From the six selected sites, vegetable parts including stems, roots, leaves, and fruits as shown in Figure 3 were washed using deionized water in order to remove visible soils and any unwanted foreign materials, weighed and shopped into small fragments before being dried in an oven at a temperature of 75°C for 72 hours. All samples were grounded to powder and sieved to obtain the appropriate mesh size and then packed and sealed for four weeks in plastic (polyethylene) cylindrical containers to reach the radioactive equilibrium [8].

2.2.2. Instrumentation

The collected samples were analyzed to determine the concentrations of ^{226}Ra, ^{40}K, and ^{210}Pb using high-resolution gamma-ray spectrometry. The used detector is a low background CANBERRA high-purity coaxial germanium (50% efficiency), with a resolution of 2 keV for the 1332 keV 60Co γ-peak, housed in a 10-cm-thick high-purity lead shield. The delivered gamma spectra by the detector are analyzed using Genie 2000 gamma analysis software. ^{226}Ra activities were determined by measuring their gamma emitter daughters ^{214}Pb (351.9 keV) and ^{214}Bi (609 keV). The photopeaks used for ^{40}K and ^{210}Pb are as follows 1460.82 keV and 46.5 keV respectively.

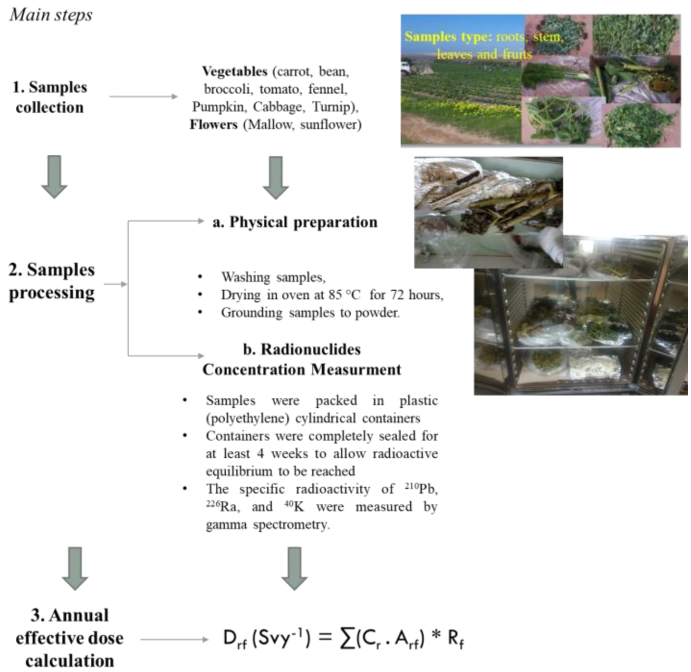

Figure 2. Flowchart of the methods followed in the present study.

2.2.3. Annual effective dose calculation

The annual effective dose was calculated using the following equation:

$$D_{rf}\,(Svy^{-1}) = \sum(C_r \,.\, A_{rf}) * R_f$$

Where :

D_{rf} is the annual effective dose; **C_r** is the effective dose conversion factor of the nuclide (r) where the factors used for estimating the internal effective doses are: 6.9×10^{-7} Sv/Bq for ^{210}Pb, 2.8×10^{-7} Sv/Bq, and 6.2×10^{-9} Sv/Bq for ^{226}Ra and ^{40}K respectively [9]; **A_{rf}** is the specific activity of the nuclide (r) in the ingested food (f, Bqkg^{-1}, fresh weight) and **R_f** is the consumption rate of the food item (f, kg.y^{-1}).

3. Results and Discussions

3.1. Activity concentrations of radionuclides in plant samples

Table 1 displays the activity concentrations of radionuclides measured in different vegetable sample parts. The minimum detectable activity concentrations for investigated vegetables were 3.44 Bq.kg-1 for (Pb-210), 2.25 Bq.kg-1 for (Ra-226), and 507.5 Bq.kg-1 for (K-40). The highest values were as follows 37.76 Bq.kg-1; 7.15 Bq.kg-1 and 1610 for Pb-210, Ra-226, and K-40 respectively. The maximum values were recorded in the roots part of the vegetables while the lowest values were recorded in the fruit vegetables. It is worth highlighting that Li et al [10] have reported higher bioaccumulation of cadmium in roots compared to fruit vegetables. In addition, vegetables can be contaminated by radionuclides through direct and indirect sources. The indirect source is when contaminants are transferred from soil through roots which may explain the maximum recorded values in vegetable roots compared to their other parts (leaves, stems, and vegetable fruit). To be noted that the radionuclides transfer factor (TF) from soil to plant for those samples was calculated and presented in El Aouidi et al [6] and showed high values for K-40 in almost all samples. Also, the highest TF values for Pb-210 and Ra-226 were higher in root sample types for almost all vegetables.

Table 1. Activity concentrations of Pb-210, Ra-226 and K-40 measured in different edible parts of collected vegetables (Bq.kg^{-1}).

Plant species	Site	Sample type	Activity concentrations		
			^{210}Pb	^{226}Ra	^{40}K
Mallow	J1	Root	37,76±0,42	7,15±0,52	806,8±46,15
		Steam+Leaves	24,31±0,49	6,89±0,47	1063±57,17
Bean	J2	Root	19,37±0,56	5±0,6	593,2±37,53
		Steam+Leaves	23,42±0,42	6,56±0,5	782,2±43,84
Carrot	SM1	Fruit	8,33±0,7	2,25±0,6	507,5±27,76
Cabbage	SM2	Root	14,72±0,52	4,31±0,61	379,2±27,54
		Fruit	3,44±0,55	2,86±0,59	975,6±27,76
Courgette	SM3	Fruit	7,43±0,9	3,4±0,58	1808,6±93,19
Courgette	OG	Fruit	12,26±0,59	3,46±0,59	1094,3±57,75
Sunflower	OG	Root	24,42±0,46	6,99±0,70	795,72±54,77
		Stem	9,91±0,61	3,25±0,63	648,3±36,61
		Flower head	6,42±0,5	5,2±0,60	831,13±48,02
		Leaves	17,16±0,59	4,8 ±0,60	511,5±33,47
		Seeds	9,15±0,82	5,15±0,60	600,4±37,38
Turnip	OG	Fruit	12,80±0,57	2,56±0,64	677,5±36,89
Broccoli	OG	Root	14,12±0,70	5,3±0,65	1038,7±60,69
	OG	Stem + leaves	7,74±0,83	4,05±0,59	880,1±49,13
Pumpkin	OG	Root+stem+ leaves	18,01±0,56	4,3±0,60	1333,9±71,13
Tomato	OG	Root+stem+ leaves	13,71±0,70	4,7±0,60	1610±85,48
Fennel	OG	Whole plant	16,84±0,50	4,42±0,57	888,8±77,09

In comparison with UNSCEAR (Worldwide median value), K-40 showed high values in the three sites of the investigation except for cabbage root retrieved from Sidi Moussa which shows values less higher than the typical value of K-40 (400 Bq.kg-1). It is worth noting that the activity concentrations of K-40 in vegetables vary according to soil metabolism capacity since plants absorb potassium from the soil. Also, the K-40 values can change geographically from one zone to another while the observed highest values of k-40 may be due also to the excessive use of fertilizers rich in potassium in agricultural areas of El Jadida as was reported in El Aouidi et al [6]. In contrast, Ra-226 shows less important values compared to those measured in vegetables from Jordan (7.1 ± 1.1 and 11.7 ± 3.4) Bq/kg [11] in dry weight sampled from agricultural areas, in Gediz River Basin of Turkey (15.96 ± 1.91 and 52.80 ± 513) Bq/kg [12]. The activity concentrations of Pb-210 show values higher values compared to those found in vegetable leaves(7 and 25 Bq kg−1) and fruit (0.4 and 2.5 Bq kg−1) in Egypt [13]. Similarly, vegetable leaves under investigation show high activity concentrations of Pb-210 ranging from 7.74 to 24.31 Bq.kg^{-1} which may be attributed to the decay of the radioactive Rn-222 and subsequent fallout of its related decay products such as ^{210}Pb. Indeed, it was reported by Laissaoui et al (2018)[14] in the surrounding area that high activities of Pb-210 were detected in Oualidia lagoon sediments mainly in superficial layers which were resulting from radioactive Rn-222 decay that showed periodic important concentrations in the overlying atmosphere.

3.2. Dose calculation

The estimated annual effective dose from the ingestion of vegetable fruits due to ^{226}Ra, ^{210}Pb, and ^{40}K radionuclides are shown in Table 2. The calculated annual effective doses for ^{210}Pb, ^{226}Ra, and ^{40}K in fruit vegetables ranged from 0.01 & 0.42, 0.0038 & 0.09, and 0.02 & 0.25 mSv/y respectively. The obtained doses of K-40 and Ra-226 for cabbage exhibited low values compared to those reported in Al-Absi et al. (2015)[11]. The total annual effective doses from all radionuclides for the carrot show a value less higher than those reported in Badghish and Hamidalddin 2022 in the Kingdom of Saudi Arabia [15] and comparable to those reported in vegetables from Iran [16] and Iraq [17]. The obtained values are almost <1 which is in good accordance with International Commission on Radiological Protection (ICRP) values. This implies that the values of natural radioactivity and annual effective dose in the investigated vegetable samples are found to be safe.

Table 2. Calculated annual effective dose by ingestion of some vegetables from agricultural areas. El Jadida, Morocco.

Vegetables	Annual Effective Doses (mSv/y)			Total annual Effective Doses from each type of vegetable (mSv/y)
	210Pb	226Ra	40K	
Courgette (SM1)	0,0204	0.0038	0,0445	0,0687
Carrot (SM3)	0,0350	0,0038	0,0191	0,0580
Cabbage (SM2)	0,0161	0,0054	0,0411	0,0627
Turnip (OG)	0,0568	0,0046	0,0270	0,0884
Sunflower (OG)	0,4262	0.0973	0,2513	0,7748
Courgette (OG)	0,0452	0,0052	0,0363	0,0867
Total annual effective dose for each radionuclide	0,5997	0,1202	0,4194	

4. Conclusion

The analysis of radionuclide activity concentrations measured in vegetables collected from three locations in El Jadida province exhibits higher values of K-40 which might be related to the extensive use of fertilizers rich in potassium in the study area.

The calculated total average annual effective dose for ^{210}Pb, ^{226}Ra, and ^{40}K in the in all samples are almost <1 which is in good accordance with International Commission on Radiological Protection (ICRP) values. It is worth noting that there is a need for further investigating the radionuclides activity concentrations naturally occurring in plants of this region in order to provide national standards values.

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